Review of Mathematical Surface Water's Hydrodynamic/Water Quality Models with Their Application on the Shatt Al Arab River Southern Iraq

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ARTICLE INFO	ABSTRACT
Keywords: *hydrodynamic,* *model coupling,* *Shatt Al Arab River,* *water surface modelling,* *water quality*	The hydrodynamic/water quality model is an important tool in water environment management. It is used to gain a deeper understanding of physical, chemical, and biological processes and to develop models capable to represent surface waters with realism. A hydrodynamic model can give essential data to sediment, noxious, and eutrophication modelling. Models enable decision-makers to select alternatives for water quality management that are superior and more scientifically justifiable. They also provide a basis for economic analysis to evaluate environmental significance and cost-benefit ratio. The presented study reviewed a variety of research that used various techniques for surface water modeling. The first section focused on the studies conducted on the Shatt Al Arab River and its branches in Basrah province southern Iraq. The second section included studies conducted on various local and global applied cases. As for the third section, it reviewed the studies that used the method of linking models to produce a more effective system, which is the approach we recommend using it in building a comprehensive model of the Shatt al-Arab river. The model will connect the HEC-RAS software, which is known for its competence in modeling complex two-dimensional situations, with the WASP program, which has a high ability to represent a wide range of water pollutants that HEC-RAS cannot represent, especially in a two-dimensional model.

1. Introduction

The hydrodynamic/water quality model has become an indispensable analysis instrument in water environment management, and the water model's derivation and application have become a popular topic in environmental engineering (Liu et al., 2021). The two primary reasons to conduct modeling are (1) to better understand the physical, chemical, and biological processes and (2) to develop models capable of realistically representing surface waters, so that the models can be used to support water quality management and decision-making. The river water quality model combines effect of its hydrodynamic characteristics and natural reaction

mechanism on the law of mass conservation. There is no universal consensus among experts on the "best" technique to modelling River, lake, estuary, and coastal waterway. Due to the interaction of flow between channel_floodplain and River_estuary dynamics, the hydrodynamics of a Riverine or coastal environment are highly complex. Therefore, simulations of channel and estuary necessitate the use of highly sophisticated models to accurately represent the flow behavior, particularly in regions where flow separation or flow around a hydraulic structure is significant. Complex surface water systems include many different components, including hydrodynamic processes. The aggregation and/or dispersion of sediments, pollutants, and algal growth are all heavily influenced by water motions at various sizes and of various sorts in addition to the temperature distribution, dissolved oxygen DO, and nutrients. Significant factors influencing the dispersion of biota and the productivity of natural waterbodies include circulation, wave events, and turbulent mixing. Sediment, toxic, and eutrophication models can benefit greatly from the information that a hydrodynamic model can offer, such as water velocity and circulation patterns, mixing and dispersion, water temperature, and density stratification. Hence, before moving on to the studies of sediment, hazardous, and/or water quality, it is essential to have a strong understanding of the hydrodynamic processes in a water system. Accurate modelling is becoming more and more important for water quality management. The adoption of the watershed/based strategy to pollution management further amplifies this dependence. Models provide decision-makers the ability to choose among approaches for managing water quality in a better, more scientifically sound manner. The models are frequently used to assess which solution will be most successful in resolving a long term water quality issue. In this application, the models must be predictive and provide situations that have not yet occurred in addition to representing the current conditions. In order for decision-makers to assess the environmental relevance of a project together with the cost/benefit ratio, models are also employed to support economic analysis. Three important factors have contributed to the tremendous development in surface water modelling:

1. A better comprehension of and descriptions in mathematics of the physical, chemical, and biological processes occurring in rivers, lakes, estuaries, and coastal waters.
2. The accessibility of fast, suitable mathematical equations that explain them.
3. Progress in computer technology.

2. Water Surface Models Methods

The most general division of modules used Surface water studies may be categorized into (Orlob, 1983; Ziemińska-Stolarska & Skrzypski, 2010):

A) Physical models (laboratory): are constructed to a specific scale and utilizes water to generate a scaled flow that can be measured and correlated with the actual water system.

B) Mathematical models: represent the water flow and other processes with a set of coupled, nonlinear, partial differential equations. Mathematical models can be categorized into:

Statistical (empirical) or mechanistic models: Statistical models are mathematical relationships derived by statistically fitting equations to observed data. An example of statistical model is one that shows a direct link between changes in the chlorophyll-a concentration (the output) at the centre of a water body and changes in the phosphorus concentration (the input) of the major feed river.

Mechanistic model is based on physical, chemical, and biological mechanisms that govern water systems. Since many of the formulas used in water quality modelling are empirical, statistical and mechanical models often work together when modelling public water systems. (Ji, 2017).

Analytical or numerical models: An analytical model has an exact mathematical solution of the governing equations describing processes in a waterbody. These models are available only for relatively restrictive conditions, usually predicting 1D problem, The Streeter - Phelps (1925) equation is an example of an analytical solution for estimating DO concentrations along a river. This model has been used for rivers during low flow periods when the flows are steady and the flow velocity can be assumed to be constant. Furthermore, the dispersion process can be neglected, allowing the analytical solution to be easily obtained (Liu et al., 2021). A numerical model is a discretized version of a set of mathematical equations, such as the continuity equation and momentum equations that describe processes in a waterbody. The computing domain is discretized into small cells, and a set of algebraic equations that may be solved iteratively or via the matrix inversion approach are used to approximate the partial differential governing equations. By submitting the model's input data and parameters into a computer, numerical solutions can be obtained.

Deterministic or stochastic models (Orlob, 1983): Deterministic models: The behavior of every variable input to the deterministic models is completely determined by the governing equations. These models, which account for the physical, chemical, and biological processes within the system as well as the fluxes of matter and energy across its boundaries, are designed to serve as both research instruments and water resources management foundations. WASP and SWAT are examples of this model type. The stochastic model includes arbitrary (stochastic) components or inputs (Zhao et al., 2022). A stochastic modelling of a River, for example, may describe flow rates in relation to mean, probability distribution, and variance. This model, however, cannot provide a specific flow rate at a specific time. Time Series Forecasting Model, Gray System Theory, Adaptive Neuro-fuzzy Inference System and Elman Artificial Neutral Network Model (ANN) are examples of this model type.

According to a number of criteria, the numerical model can be categorized as

1. Numerical method, including finite difference, finite element, and finite volume.
2. A time-differencing system that includes explicit, implicit, semi-implicit, and other terms.
3. Flow condition: steady-state or time-dependent (dynamic). Also be categorized as:

Zero Dimensional Model: The main goal of a zero-dimensional model is to figure out how bad a problem with waste release is. Therefore, the contaminants have temporal variation only (Khudair, 1999).

One Dimensional Model: Solving the 1D St. Venant equations is still the most common way to make computer models. General codes like HEC-RAS, which was made by the U.S. Army Corps of Engineers, and MIKE 11, which was made by DHI, are two of the most famous 1D models. (Munoz, 2017).

Two Dimensional Models: It can be divided broadly in two main classes:

➢ *Two Dimensional plan view or depth averaged model* allows concentration variations in longitudinal and lateral directions. It is assumed that the vertical length scale is much smaller than the horizontal length scales. As a consequence, the vertical velocity is small and pressure is hydrostatic, leading to the differential form of the SW equations (Munoz, 2017).
➢ *Two Dimensional side elevation or width averaged model* allows concentration variations in longitudinal and vertical variations. Where density stratification, the transverse variation in constituent concentration may be neglected specially in narrow water body (Al Murib, 2018).

Three dimensional numerical models permit the prediction of the 3D spatial distribution of the concentration field of contaminants. (Luo et al., 2021).

In the last decades rapid development of mathematical modelling of water resources quality has been observed. Several computer models have been designed which are successfully applied in practice in many countries (Ziemińska-Stolarska & Skrzypski, 2010). Review research studies from the web of science focused on the fate and transport of water quality modules in waterbodies, such as EFDC, CE-QUAL-W2, WASP, Delft3D, AQUATOX, and MIKE, are listed in Table 1. The highest models utilized in uses and citations were EFDC and CE-QUAL-W2. The United States and China were the most frequent users of such models (Bai et al., 2022). Table 2 compares and evaluates the dimensions, state variables, applicability, advantages, and limitations of various models.

Table 1.
Research records about water quality modeling (2001 – 2022)

Model	EFDC	CE-QUAL-W2	WASP	Delft3D	AQUATOX	MIKE
Article/review	210	179	143	74	50	132

Table 2.
Comparisons of different models' features

Model	Dimension	Advantages	limitations	Area of application
AQUATOX	1D	It has sensitivity analysis and uncertainty analysis tools. It can simulate toxicity, bioaccumulation, bio-communities under different environmental changes. It includes a sediment diagenesis module for remineralization.	It cannot simulate metals. It is suitable for a well-mix aquatic system.	coastal areas estuaries lakes rivers streams reservoirs
CE-QUAL-W2	2D	It includes a sediment diagenesis module for remineralization. It permits large time-steps during a simulation decreasing computational time.	It is inappropriate for waterbodies exhibiting significant lateral variations. Simplistic sediment oxygen demand.	estuaries lakes rivers reservoirs
Delft3D	2D/3D	It supports structured or unstructured grids. It permits users to define functions or processes in a simulation.	It doesn't include macro types or rooted plants.	coastal areas estuaries lakes rivers reservoirs
EFDC	1D/2D/3D	It includes a sediment diagenesis module for remineralization.	Zooplankton and detritus are not included.	coastal areas estuaries lakes rivers reservoirs wetlands
MIKE	1D/2D/3D	Users have flexibility to choose the processes in a simulation. It provides an auto calibration module	It doesn't include macro types or rooted plants.	coastal areas estuaries lakes rivers reservoirs wetlands

Model	Dimension	Advantages	limitations	Area of application
WASP	1D/2D/3D	It includes a sediment diagenesis module for remineralization. It has uncertainty analysis tools.	It requires external hydrodynamic models for flow information.	coastal areas estuaries lakes rivers reservoirs wetlands
HEC-RAS	1D/2D for Hyd. 1D for WQ.	It includes sediment transport computations, and water temperature modeling. does not need any additional programs to display the results	It is inappropriate for waterbodies exhibiting significant lateral variations. It is suitable for a 1D water quality only. limited number of water quality constituents	Rivers Channels Floodplain

3. Applications of Water Surface Modelling

The following sections will review a variety of research that used various techniques previously described for surface water modeling. The first section focuses on the studies conducted on the target study area of this study, represented by the Shatt al-Arab river. The second section includes studies conducted on various local and global applied cases. As for the third section, it will review the studies that used the method of linking models to produce a more effective system, which is the approach we take in building a comprehensive model of the Shatt al-Arab river.

3.1. The Studies of Modeling Shatt Al Arab River

The Tigris and Euphrates Rivers meet near Al- Qurna district in southern Iraq to form the Shatt al-Arab River (Figure 1). The Shatt al-Arab River is a 192-kilometer-length tidal river that flows south-eastwards, passing through Basrah and then, discharging into the Arabian Gulf (Ahmed Naseh Ahmed Hamdan, 2016). The province's seven creeks (Jubyla, Muftya, Robat, Khandek, Ashar, Khora, and Saraji) are linked to the Shatt al-Arab River and they are affected by the tidal phenomenon. The river's width changes along its length, from 250 to 300 meters at the Euphrates-Tigris meeting and reach to 600 meters around the town of Basrah and 2000 meters at the estuary(HAMDAN, 2015). For the last 95 kilometers of its course, the River forms part of the border between Iraq and Iran(ABDULLAH, 2016). In addition to transportation, Shatt al-Arab River has an important role in delivering water for domestic use, irrigation, and manufacturing(Ahmed Hamdan, 2018). The river serves as the region's primary supply of water it promotes agricultural and industrial operations, as well as navigation and ecological biodiversity. The water is diverted for irrigation purposes, mostly in the upper stream for grain production and in the lower course for palm forest. Several water treatment plants along the river divert water for household use. Accordingly, The river plays a crucial role in the economy and ecology of the region and faces a range of environmental challenges, including pollution from oil spills, agricultural runoff, and sewage discharge. So, the pupose of this work The main objective of this work is to collect most of the studies that dealt with the river and similar studies that used various analytical methods to reach the best description of the hydrodynamic behavior of the river. One of the most important outputs of this review is to determine the type of appropriate model for the river as a first step to study the water quality due to the great importance of the river in the region, as well as identifying the sources of pollution and their type.

Figure 1. The Shatt al-Arab River with main city locations

Hassan K. Al-Mahmoud et al (2011) made a one-dimensional modeling system performing an implicit finite difference computation of unsteady flow in rivers based on the saint Venant equations and it was executed by Mike 11 hydrodynamic (HD) where the packaged software is introduced in Marine Science Center, Basra University in Iraq. It was limited to the northern 64 kilometres of the Shatt Al Arab River, from the Qurnah confluence (upstream river) to the Maqal port in Basrah (downstream river). The study area grid was generated from a TM Landsat Satellite image, and five cross sections were distributed along the studied river segment to provide the necessary data for creating a network file for simulation processes. The upstream and downstream boundaries are open, with a constant discharge (Q) value of 300 m3/s, and a time series file of Shatt Al Arab River downstream water level (H) was created over a 30-day period. The results represent five important sites on the river that could be reflected in the variations, resulting from the interaction of influence between the discharge (Q) and water level (H), (Hassan K. Al-Mahmoud 2011).

Mohammad Moyel (2014) presented in his paper the outputs of statistical analysis of a number of physicochemical water quality parameter, that assembled on a monthly basis between 12/2012 and 11/2013 at seven sample locations distributed over the Shatt Al-Arab River in order to obtain a good knowledge to detect spatial similarity for grouping sampling stations located within the monitoring area, and determine the factors or sources responsible for water quality variations in the quality of the river. Multivariate statistical techniques; principal component analysis (PCA) and cluster analysis (CA) used to evaluate and interpret a data set on the Shatt Al-Arab River's water quality for a total of seventeen parameters. Physical and chemical characteristics of water include water temperature (WT), electrical conductivity (EC), salinity, pH, turbidity, DO, biochemical oxygen demand (BOD5), nitrite nitrogen (NO2-N) and nitrate nitrogen (NO3-N). The results of PCA recognized four latent elements that describe 78.64% of the total variance of the data set. These factors are: Water visibility, Seasonal impact of temperature and organic pollution, Nutrient content and water mineralization. Four distinct groupings of similarity between the sample sites were revealed by CA, which reflected the various physicochemical characteristics and categories of natural background sources, (Moyel, 2014).

Ahmed Naseh (2016) found hydrodynamic simulations of river water for whole length of 200 km by controlling gates in the Shatt Al Arab River. The steady flow analysis was performed for the flow normal depth case, as well as for several upstream discharge cases in and various recorded water level data in the River downstream from Sep. 2009 to Jan. 2015). He suggested a proposed location of the regulator at a distance of about 3 km upstream of Abu Flus port. He

suggested simulating the water surface level in the Shatt Al Arab River using HEC-RAS software and three distinct sluice gate opening scenarios. These cases were examined under two tide conditions (the highest high water level, HHWL, and the lowest low water level, LLWL) in the Shatt Al Arab River's tributaries. Total Tide software was used to determine the tide in the estuary of the River. The software indicated 3 m and 0.7 m for the greatest high water and the lowest low water respectively. The study also examines six cases of flow rates upstream of the Shatt Al Arab River, where high values of discharge were used to ensure that the openings functioned under the most extreme flood conditions. When all the gates are fully opened up, the stage has risen by about 1 m compared to what it would be like without the dam. By building the wall, the salty wedge from the seawater that mixed with the fresh water is stopped. The proposed site of the gate lets ships go to the Abu Floos port and gives water to farms in Abu Al Khaseeb, the centre of Basrah, and the Qurna region, (Hamdan, 2016).

Abdullah Ali Dinar (2016) examined the availability/ quality of water and marine penetration in the Shatt al-Arab River through systematic monitoring and modelling. Various combining modelling approaches employed in this study supported by data field recorded by ten sensors (divers) which installed, on 200 Km length of the estuary and River, and well maintained and regularly calibrated. Hourly observations of stage, salinity, and temperature have been established as part of a systematic monitoring program. The movement of seawater was simulated using an analytical 1D salt penetration model. Between March 2014 and January 2015, the model was implemented to analyze the seasonal distribution of salinity during under various river conditions such as wet/dry period and spring/neap tide. The mean monthly salinity ranges for stretches R1, from Qurna to Shafi, R2, from Makel to Abu Flus, R3, from Sehan to Dweeb, and R4, near the estuary, were 1.0-2.0, 2.0-5.0, 1.0-12.0, and 8.0-31.0 ppt, respectively. He developed a predictive model that accounts for the specific tidal, seasonal, discharge variability, and geometric characteristics of the Shatt Al Arab River in order to provide a more physically estimate of the intrusion distance of sea water. He calculated seawater intrusion lengths, which varied from 38 - 65 km through the time of study. He expected the length of saltwater intrusion to reach 92 km at extremely low river discharge, (ABDULLAH, 2016).

Abdul-Razak M. Mohamed (2016) showed how geographic information systems (GIS) and spatial analysis methods could be used to make the description of space and time-based distribution of some water characteristics and make predictions about them. From December 2011 to November 2012, the study was done. He chose three places for his work based on what the area was like. Station 1 was near Al-Dayr Bridge, station 2 was close to Ashalha Island north of Sindbad Island, and station 3 was close to Al-Sahel Land/Abu Al-Khasib district. Monthly water samples were collected from three stations in the middle of the river by lowering a sampling container approximately 15 to 25 cm below the surface. The results indicated that water temperature varied between 11.3 and 35.7 C, salinity varied between 1.37 and 3.13, and pH varied between 7.33 and 8. TDS ranged from 1985 -7131 mg/l, and DO was between 6.1 and 9.5 mg/l. Trans. ranged between 38.3 and 72.31 cm. The salinity progressively increased as it approached station 3. This is due to a combination of factors, including a decrease in the discharge of the Shatt Al-Arab as a result of falling water levels in the Tigris and Euphrates. While a notable increase in salinity was observed at station 1 compared to other stations, the cause was attributed to a lack of saline sea front penetrating from the Gulf during ebb, as determined by the sample collection, (Mohamed et al., 2016).

Hamdan and Dawood (2016) predicted the future TDS of Shatt Al-Arab River using ANN. Some water quality parameters, like hydrogen power (pH), electrical conductivity (EC), total hardness (TH), calcium hardness (CaSO4), magnesium hardness (MgSO4), chlorides (Cl), sulphates (SO4), and turbidity (TU) were used as inputs for the ANN, and the model's output was the total dissolved solid (TDS). During the confirmation process, the coefficient of

correlation (R) and the mean squared error (MSE) were equal to 1, and (0.075) respectively. This study backs up the idea that the ANN approach is a good way to describe the complex and nonlinear behaviour of TDS in Rivers under different situations. It had been shown that the TDS levels in the Shatt Al-Arab River are high. This means that the Shatt Al-Arab River's water is brackish to salty, (Hamdan & Dawood, 2016).

Abbas (2017) applied one dimension/unsteady case to study hydrodynamic and TDS simulation of the river water by using HEC-RAS in Shatt Al-Arab River and Tigris-Euphrates rivers. Daily measurements of discharge, stage, and TDS were obtained in 2014 at various sites along the Shatt Al-Arab and Tigris-Euphrates confluences. 63 cross sections of the Tigris, 26 cross sections of the Euphrates, and 90 cross sections of the Shatt Al Arab river are accessed, with a distance of approximately 1000 metres between each cross section. Based on previous research, he assigned 0.033 and 0.06 values of roughness coefficient to the River and its banks, respectively. The value of $53m^2/s$ for the model's dispersion coefficient provided the closest accord between the computed TDS from simulations and observations. The result indicated that observed and simulated data were in great agreement, with a minimum correlation (R) of 0.825%. As of September 8, 2014, the effect of saline wedge intrusion from the Arabian Gulf with elevated TDS had reached the site of confluence, (Abbas, 2017).

Noor A. Eraibi (2017) focused in this work on assessment the effects of installing RO units on Shatt Al Arab River's water quality measured in forms of salinity. 1D flow model of the River was conducted by using HEC-RAS software as well as water quality in term TDS distribution. Four cases of Shatt Al Arab River flow were considered, the maximum and minimum values of Tigris River's flowrates, for the years 2009, 2010, 2012, 2013, and 2014, and tidal ranges. In this work, the considered reach of Shatt Al Arab River started from Al Hartha city and ended at Al Fao city (147 km). All of the River's lateral branches had been ignored. Sixteen Water Treatment Plants (WTPs) were considered as a point pollutant source of TDS as a result of suggested RO units. The unsteady flow of the research region was simulated for two states: (1) no brine water outlets (the existing status) and (2) brine water outlets present (the projected status following the installation of RO units). The findings revealed that installing RO units in Basrah's 16 WTPs will reduce the amount of water generated. As a result, these plants' capacity must be enhanced. If the capacity of Basrah's 16 WTPs is expanded, the maximum TDS level rises but remains below than the US EPA's TDS limit, (Eraibi, 2017).

Mudhar Hassan Gatea (2018) looked at the quality of the water in the Shatt Al-Arab River. He took water samples from six stations in months January and April of year 2013 and used (pH, DO, PO_4, NO_3, K, Mg, TH, SO_4, CL, TDS, EC, and alka.) to figure out the purity of the water was. The parameters were analysed and evaluated separately in accordance with World Health Organisation (WHO) recommendations for drinking water. The average electrical conductivity value was approximately 6800 S/cm, which exceeds the WHO-recommended value of 2000 S/cm. In all stations, the concentration of sulphates is nearly above the WHO-recommended 250 mg/L. This examination revealed that the water quality of the Shatt Al-Arab River is unsuitable for human consumption, (Gatea, 2018).

Al-Aboodi et al. (2018) investigated the suitability of the Shatt Al-Arab River for different uses near Hartha and Najibia power plants through physical and chemical analysis [T, pH, EC, Cl^-, Na^+, K^+, Ca^{+2}, Mg^{+2}, HCO_3^-, NH_4^+, NO_3^-, NO_2^-, SO_4^{-2}, Fe^+, K, TH, and BOD_5] Using the water quality index (WQI), organic pollution index (OPI), sodium adsorption ratio (SAR), and sodium ion percentage (Na%) between August 2016 and January 2017. Three sampling locations were chosen: S1 is in front of the Al Hartha power station, S2 is 1000 m north, and S3 is 1000 m south. Water samples were taken in front of the Al Najibia power plant (S4), 1000 metres north of it (S5), and where the Shatt Al-Arab and Qarmat Ali rivers meet (S6). In

summer, the percentage ratio of water quality factors index near Al Hartha and Al Najibia power plants increased by 13.22% and 9.69%, respectively, compared to the north regions of these plants. The WQI OF Hartha and Najibia power plants rised 17.93% and 15.92% respectively in winter compared to the north portions, (Al-Aboodi et al., 2018).

Ahmed Naseh et al. (2020) focused on monitoring the movement of seawater from the Arabian Gulf to the Shatt Al-Arab River. Utilising the HEC-RAS 5.0.5 software's one-dimensional transport model, he determined the dynamics of TDS in the River. Using HEC-RAS software, a finite-difference model was utilised to simulate the tidal flow. The river was divided into four reaches: the Tigris, the Euphrates, the Shatt Al-Arab, and the Garmah. The origin is located near the estuary south of the city of Basrah. The hydrodynamic model was set up for 10-month of operation with the hourly observed water level and the daily TDS values. Four cases were used to figure out how much salt got into the River. These were the low and high discharges from the Qalat Saleh regulator at high and low tide, which were $29m^3/s$ and $103m^3/s$, respectively. When the flow was high, the TDS was between 3000 and 4000 mg/l at the LLWL and the HHWL respectively. When the flow is low, the TDS is between 1000 and 2000 mg/l at the LLWL and the HHWL, 150 km from the mouth. It can be said that increasing the amount of freshwater coming in to $103m^3/s$ will stop salt water from getting into the centre of Basrah city at both low tide and high tide, (Hamdan et al., 2020).

Safaa Al-Asadi et al. (2020) evaluated the River's water quality by investigating the influences of the variations of heavy metals levels. They test the surface water with bed sediment at four stations (Qurna, Basrah, Abulkasib and Fao) during the months 07 and 11 of the year 2017, and 02 and 04 of the year 2018. They tested many of heavy metals in addition eleven physiochemical parameters including TDS, PH, DO, nitrate, chlorides, turbidity, total hardness, electrical conductivity and alkalinity. Data were analyzed statistically using SPSS version 24.0. The results showed that the maximum value of TDS was in Fao station where it reached 42,844 mg/l in the summer because of the effect of salt from Arabian Gulf. The findings indicated that most ions in the Fao area have a 200% or more rise in concentration, particularly during the summer. These results suggested that surface runoff from agricultural areas after rain and atmospheric deposition of gaseous emissions from oil production and power generators were the main causes of heavy metal pollution of rivers, (Al-Asadi et al., 2020).

Zahraa Q. Lateef et al (2020) illustrated the potential application of spatial analysis techniques employing interpolation (Kriging) via geographic information systems (GIS) to classify the water assessment characteristics distribution, temporally and spatially, in order to find the water quality parameters of the Shatt Al-Arab River. From December 2018 to October 2019, eight major parameters of water quality and 3 heavy metals were checked. Based on the availability of data, TDS, CL, SO4, and TH were compared to previous measurements from 2014 to 2018. In order to analyse water quality parameters, geochemical characteristics were also studied. Eleven stations collected water samples over the course of four seasons (winter 2018 to autumn 2019). TDS ranged between 950 and 8500 mg/L, TH between 400 and 2394 mg/L as calcium carbonate (CaCO3), SO4 between 149 and 1602 mg/L, and CL between 330 and 3687 mg/L, according to the results. Also, the results indicated that the Shatt Al-Arab River had a high salinity and a low risk of sodicity. This study also revealed that the study area is bounded by Al Maqal station and Abu Flus station, where the Arabian Gulf's saline marine water continues for extended periods. This analysis suggests constructing a dam downstream of the Shatt Al-Arab River (at Abu Flus Port) to prevent Arabian Gulf saline water from entering, (Lateef et al., 2020).

Najla AL-Amiri and Disher (2021) studied the Hydrochemical of Shatt al-Arab River. Ten stations were chosen along the River from north to south. Samples were collected within six

months, the first three months were January, February, and March, in the winter season, and the remaining three months were June, July, and August of the summer season for 2018. The results showed seasonal and spatial variations with different sampling stations, and the study showed the existence of two main areas in the river, one of which is characterized by freshwater, which is located in the northern part of the river as a result of being affected by the freshwater of the Tigris River, and the other with salty water located south of the river affected by the saltwater from the Arabian Gulf and coinciding with salinity coming from Hor Al-Hammar through Al-Musahab and Al-Sallal rivers across Al-Garma River that flows into Shatt Al- Arab, while there is secondary transitional area, which is the freshwater coming from the top of the river's path that mixed with the salty water from the bottom of the river. Two guides were adopted to assess the validity of river water for agricultural purposes;(1) the USDA Salinity Laboratory Classification, the water class for all stations were (C4S1*), and (2) the United Nations Food and Agriculture Organization where the water was classified within the water category with acute problems of salinity and mild to moderate problems in relation to the sodium adsorption rate (SAR), (AL-Amiri & Disher, 2021).

* C4S1: Very high-salinity water (C4)/Low-sodium water (S1) (Glover, 1996).

Mujtaba, A. T. and et al. (2021) used Cluster analysis to classify the quality of the water in the Shatt Al-Arab River so that it could be used for drinking. Three stations have been selected prior to water treatment plants. One of them is St.1, which is upstream of the River and near to the main water treatment plant. It is affected by the wastes of small industries that haven't been handled. St.2 is in Salhia near to the Al-Bradhiah water treatment plant, 4 km downstream of St.1. This station gets a lot of water pollution from cattle bathing and washing clothes in the River. St. 3, which is in Abu Al-Khaseeb near to the Mhellah water treatment plant, 7 km downstream of St. 1. 11th physico-chemical parameter (Water temperature, Salinity, pH, Transparency, DO, BOD5, TDS, NO_3, NO_2, PO4, and Alkalinity (Talk) of the stations are studied and monthly collected during Dec. 2015 to Nov. 2016. The eleventh physico-chemical parameter was classified into three clusters by cluster analysis: first, DO and Trans., second, pH, and third, the remaining studied water parameters. The mean values of the investigated physicochemical parameters were analysed using principal component analysis (PCA). Hierarchical cluster analysis (HCA) was used to objectively define the categories of stations, and the results noted 3 sources for water quality that contribute to the overall water quality of the River, (Mujtaba et al., 2021).

Alya A. Mohammed (2022) assessed the suitability of Shatt Al-Arab river's water for different purposes such as drinking and irrigation. The return flows from industrial factories, power plants Hartha and Najibia as well as Al-Hartha Paper Mill, are directly discharged into the River. The environmental impact of those factories was examined through physicochemical analysis of; temperature, pH, EC, TDS, Cl^-, Na^+, K^+, Ca^{+2}, Mg^{+2}, HCO_3 TH, BOD_5, DO, COD. Samples of water were collected monthly from the River starting from Nov. 2016 up to Oct. 2017. BOD5 concentrations near factories indicated hazardous, contaminated water that requires costly remediation to be used for drinking. Sodium concentration is a crucial irrigation factor, represented by SAR and SSP. As SSP levels in the water close the factories exceed 75,73 %, soil structure could deteriorate and agricultural land could be damaged. The increased levels of COD and BOD_5 may pose a risk to aquatic life. The work revealed contaminated water close industrial areas. Then, it was recommended to collect regular data on the river's water quality in these areas, (Mohammed & Al Chalabi, 2022).

Al-Asadi et al. (2022) investigated dimensional variability of the temporal, spatial, and vertical salinity in the transitional zone between the water of Shatt Al-Arab River and the Gulf (in the estuary region) that helps to show the extent of the saltwater penetration into the river during

the year 2019 to 2020. The research utilised four water sampling stations (Al Ashar, Al Seeba, Al Fao, and Rass al Bisha) distributed along the southern river part. During tidal conditions, TDS was measured in the field by collecting water samples along the water column at a rate of 2 meters from the surface to the bed. He used mathematical of onedimensional equation of salt balance (diffusion–advection equation) to calculate stratification parameter and distance of seawater intrusion depending on field data. The weak point of this equation was derived based on the hypothesis that the depth and width of the river is constant (Mikhailova, 2013). The work was divided the River's mixing area into four distinguish regions; strong, weak, partial, and moderate stratification. The longitudinal distance for the saltwater penetration into the Shatt Al-Arab River was approximately between 83.7 and 112.4 km through the winter and fall respectively. It appears that the estuary position is shifting toward the Basrah center because of the predominance of saltwater over fresh water in this section. TDS concentration in river water has a spatial pattern that tends to increase concentration averages south towards the Gulf, (Al-Asadi et al., 2022).

The water quality of the main body of Shatt Al Arab River has been studied extensively by many researchers. In contract, very few researchers considered the effect of main branches which have several natural potentials to play a major role in the revival of the Basrah city namely; Sarraji, Khora, Ashar, Khandak, Robat, and Jubyla on water quality of Shatt Al Arab River such as:

DoaAbul et al. (1987) performed this study to assess the efficacy of the planned flushing system by examining the water quality of these branches. The water quality parameters presented in the study were: DO, pH, hydrogen sulphide, ammonia, COD, BOD, dissolved silicates, dissolved reactive phosphate, nitrate, nitrite, and chlorophyll-a. It was discovered that their waters subjected to extremely low concentrations of DO and relatively high concentrations of BOD and COD. Due to the high yearly volume of water discharged by the Shatt al-Arab River, the majority of constituents in this study had no discernible influence on the water quality characteristics. The statistical analysis displayed that not significant different, P value less than 0.05, between the samples of surface and just above the bottom, so they concluded that the water's column was homogeneous. Based on the total amount of organic matter in sediment cores, they suggested that the organic sludge on the bed of Basrah Branches be dredged to a depth of at least 50 cm, (DouAbul et al., 1987).

Taobi and Al-Hejuje (2000) investigated the distribution of four heavy elements (Co, Ni, Mn and Fe) in dissolved and particulate phases of water from five selected stations in Al-Ashar and Al-Khandak canals which are connected with Shatt Al-Arab river as well as sediments of Ashar and Khandek branches. The results showed that the concentration in the limit range of the world standards for inland water. The concentration of all studied elements were found to be higher in particulate matter compared to in dissolved phase of water' This could be attributed to the ability of particulate matter (specially the living phytoplankton) to concentrate heavy elements in their bodies more than the surrounding water, (Taobi & MM, 2000).

Al-Imarah et al. (2008) measured the concentrations of trace metals (Co, Cu, Ni and Zn) in both dissolved and particulate phases in water of Khora, Ashar, Khandek, Robat, Jubylah and Shatt Torek branches during spring and summer of 2006. The results showed that the levels of metals were higher than most previous studies at the same sites. It is appeared that all studied branches are highly polluted and water appears highly turbid, viscose and greenish in color due to the expected abundance of phytoplankton, (Al-Imarah et al., 2008).

Khudhair (2015) used the Canadian WQI to evaluate the water quality in the main tributaries of the Shatt Al Arab River. This includes the Al-Saraji, Al-Khora, Al-Ashar, Al-Khandek, Al-Robat, Al-Jubyla, and Shatt Al Turk branches. The evaluation considered for domestic,

recreational, and aquatic life support purposes. Water samples were taken during high and low tide times on 17-June to 16-July depended on tide tables of 2013. The samples were analysed for 10 factors; turbidity, TDS, pH, BOD, DO, NH_3, total/ faecal coliform bacteria, NO_3, lead, and sulphate. At five stations in each branch, water samples were obtained. The results of water quality analyses conducted on all branches under consideration through flood conditions are not better to those got through ebb conditions. Given that the derived value of the WQI for the major branches of the River fluctuate across the range for various applications. The results concluded that the water quality in the main branches of the River was of poor quality. She discovered that the DO concentrations in the waters of Al-Khora, Al-Ashar, Al-Khandek, Al-Robat, Al-Jubyla, and Shatt Al Turk tributaries are below the allowable limit and were correlated with increased BOD concentrations, (Khudhair, 2015).

Hamdan, Dawood et al. (2018) used WQI to characterize the Shatt Al Arab River's pollution level, and a GIS was used to generate a WQI plan. Moreover, the work identified the key pollutants influencing the River's water quality along its entire length. WQI was developed utilizing a variety of water quality parameters, including pH, temperature, DO, BOD5, COD, $NO3^{-2}$, $PO4^{-3}$, TDS, TSS, E.C, and Turbidity, which were observed at (37) locations distributed on the River and its major tributaries within the city of Basrah. On the locations of the branches, poor water quality was observed. In addition, disposal wastewater, Particularly unlawful industrial effluent and untreated sewage, was the primary cause of the River water contamination, (Hamdan et al., 2018).

Abed (2020) used 1D unsteady flow model by HEC-RAS software to simulate water movement in the major six branches of the Shatt Al Arab River. He proposed the right planning and design solutions to bring these rivers back to their natural state, reduce their pollution, and increase their self-purification efficacy. Waste water discharges are transported to the primary river system through pipelines of varying diameters. Using Differential GPS, he produced stream shape data (cross sections) throughout a topographic survey of the branches. The distance between cross section and another didn't exceed 100m. each cross section have 6-8 station. The findings revealed that for the 3 River pairs Al-Saraji-Al-Khora, Al-Ashar-Al-Khandaq, and Al-Rubat-Al-Jubyla, the sufficient time for self-purification was (18.11, 17.29, and 18.29 hours, respectively). While the river's sufficient distance was (5.8, 5.71, 4.76 Km) respectively for self-purification, (Abed, 2022).

3.2. General Applications of Water Modelling

Khudhair (1999) developed a two dimensional, plane view mathematical model to simulate pollutants transport in Shatt Al-Basrah canal and Khour Al-Zubair estuary in southern Iraq. The model, labeled FESTS, written in FORTRAN language, which has two components, one of them, a two-dimensional plan view, simulated the tidal varying flow velocities and water levels in the Shatt Al-Basra canal and Khour Al-Zubair estuary (hydrodynamic model). The second component simulated the concentration field of different constituents including industrial pollutants discharges from three factories into the studied waterbodies (water quality model). The model used as predictive tool of the three plants (steel, petrochemical, and fertilizer plants) as a point source of pollution. The shallow water and transport equations were solved by the finite element method using Calerkin weighted residuals. Field data were collected during two stages, July-1997 and April-1998. The measured physical characteristics and laboratory work include flow velocity, flow depth, water temperature, salinity, ON, NO2, NO3, NH4, P, CBOD, chlorophyll. The results showed that the impact of discharging the waste on water quality increased with increasing tidal range. Also, this impact was reduced when the waste discharged during ebb period and when output location of petrochemical plant was

transported to Khour Al-Zubair estuary. Moreover, she found that the degree of flexibility depend hydrodynamic conditions and method of discharge. Other findings: the most stable solution was achieved by setting the implicitness value equal to one (fully implicit finite difference). The effect of downstream water level on the spreading of different pollutants depends on tidal condition and extends to the whole domain of the study area, (Khudair, 1999).

Sharma and Singh (2009) illustrated the utility of STREAM II, STREAM II designed at Indian Institute of Technology, Bombay as a modelling program to describe the pollutant load owing to organic matter in the Yamuna River, Delhi, India. The investigation was conducted between 1995 and 2005. Model simulated the DO and BOD parameters in a 2D Steady state mode Model analysed the river section as a series of reaches. It was presumed that reaches represent river segments with uniform conditions (geometric, hydraulic, and chemical–biological coefficients). The model was simulated and calibrated using primary data from the field of water quality and secondary data from the Central Pollution Control Board. The model provided a reasonable correlation between calibrated and observed data, thereby demonstrating its validity. The BOD concentration decreases gradually downstream due to natural self-purification phenomenon. There is a sharp increase in BOD as soon as drains join the river throughout the stretch. It was observed that for all the years (1995–2005), the levels of BOD were far above the standard levels, (Sharma & Singh, 2009).

Chen et al. (2012) carried out an extensive investigation of pollution sources. By using WASP, they established strategies of water quality control in Carp Lake, Taiwan. The field work investigated the effect of both PS and NPS pollutants on water quality. BOD, TP, NH_3–N load contributions have been recorded for each source type. The eutrophication level of the lake was assessed based on the Carlson's Trophic State Index (TSI). The TSI in Carp Lake varied from 61.9 to 69.2, indicating severe eutrophication. The findings showed that the BOD productions as a result of PS and NPS were 45.9 and 55.1%, respectively and NPS produced about 80 % of TP because of the fertilizer used in the agricultural areas. Moreover, the contribution percent for NH_3–N load was 55.5 and 44.5%, by point source and NPS respectively, (Yen et al., 2012).

Alam et al. (2013) assessed the effects of rising temperature and solar radiation on the water quality of the Sitalakhya River in Bangladesh using WASP. Nine state variables: DO, BOD, NH_3, ON, NO_3, IP, OP, TSS, and PHYTO were included in the development of model. The total daily solar radiation, photoperiod, wind speed, water temperature, and air temperature are some of the important environmental variables connected to the water quality model. Using the water quality data from 2008 to 2009, a 1D quasi/steady state model was calibrated and verified. Providing REgional Climate for Impacts Studies PRECIS, a regional climate model was used to predict the weather for the years 2030, 2050, and 2070. Since, the model used to predict the effects of the temperature variation and solar radiation on the Sitalakhya River's water during the arid periods of these years. The model predicts a gradual decrease in ammonia-nitrogen and BOD5 as the temperature rises. Due to the rise in temperature, nitrification and BOD decay rates are anticipated to accelerate. It is anticipated that the orthophosphate concentration will decline due to phytoplankton's increased absorption of orthophosphate in the upper river section. The model predicts a gradual decrease in NO_3 due to a greater assimilation by phytoplankton, which it increased as a result of increasing temperature and solar radiation. As phytoplankton chlorophyll-a concentrations increase, the output of the model predicts that DO concentrations will increase due to increased DO production via algal photosynthetic processes, (Alam et al., 2013).

Chuersuwan et al. (2013) created, Using the water quality model WASP, a model to empower local governments on water management in the basin of Lamtakhong River in Thailand. The model is used to evaluate cause/effect linkages between external factors such as pollution loads

and fluxes, and it is a basic tool for forecasting future changes in water quality caused by changes in waste water effluents. The model was used a 1D steady flow to compare how changes in pollution loads affect DO content. The adapted Streeter-Phelps balance equations were used to model the dynamics of DO. Using monthly weather and water quality data from 2008 to 2009, WASP was adjusted and proved to be accurate. It was discovered that the model can account for variation and predict levels of DO in River systems. It was concluded that "business as usual" will have a detrimental effect on water quality in the future, resulting in some downstream places having DO levels that were close to zero. However, the water quality of the river would be considerably improved with a 50% decrease in pollutants, (Chuersuwan et al., 2013).

Marvin and Wilson (2016) showed how the Salmon River estuary and its branches were modelled using the most up-to-date 1D, 2D, and 3D modelling tools as part of a full study of flood risk. A combined 1D and 2D model adopted to simulate the interaction between the Rivers and tide and floodplain hydraulics. The models, MIKE21 and MIKE3, simulated the tidal entry and amplification between the Fundy Bay and the estuary of Salmon River, in addition to sediment load in the estuary. These models were used in tandem to measure the flood extents of the Salmon River estuary and its tributaries, as well as to assess the effects of over 40 flood mitigation solutions. The Coriolis Effect had a strong impact on the tidal dynamics in the Bay of Fundy. The Bay of Fundy's water levels raised by 0.52 m due to Coriolis forces. 1D modelling had significant gains in stable, fast, and representative results for unidirectional flow paths. In contrast, 2D modelling found to be necessary only when the flow paths were poorly defined, (Marvin & Wilson, 2016).

Alzahrani (2017) focused on the comparison of 1D and 2D models, by using HEC-RAS software, for a stage in the channel and the floodplain. The models were tested in Montgomery County, Ohio, on the Bear Creek and Great Miami River. The two models were evaluated by comparing them to observed inundation extent. He used LiDAR topographic datasets and different cross-sections provided HEC-RAS. He used USGS station to get flow data. The 1D model was having high sensitivity to Manning coefficient. The results were essentially convergent between the results of two models, indicating that the procedure of the 1D model needs greater hydraulic knowledge than the use of the 2D model. Higher roughness values led to a greater WSEL and inundation area, (Alzahrani, 2017).

Ramos et al. (2020) performed in his study a simulations for the dispersion of Chrome III (Cr III) pollutant, non-biodegradable mineral, it can convert into (Cr VI), which is very dangerous to the environment and people, in the Bogotá River, Cundinamarca, Colombia. WASP model was simulated Cr III dispersion at the study conditions. The modelling results also showed that the main factors were the dispersive coefficient, the flow, and the geometry of the system. Fischer equation adopted to estimate dispersion coefficient for this study. The simulated Cr concentrations were more sensitive to changes in the water flowrates. Index of agreement value, 0.853, indicated a high correspondence between observed and simulated data of Cr concentration in the water stream, (Ramos-Ramírez et al., 2020).

3.3. Model Coupling Applications

A significant development in surface water quality modelling is model coupling. The integrated modelling approach is more complex and challenging than the traditional water modelling. Various sources of pollutants and various transport processes are involved in the fate and transport simulation of pollutants of water bodies. In general, the major challenges are the scarcity of measured data, bathymetry information, model parameter estimation, computational time (Datta et al., 2018). WASP was designed to simulate water quality rather than

hydrodynamics. The hydrodynamic equation for simulation of the water body was initially constructed and solved in the early WASP model study, and the calculation results were then utilised as input data for pollution transport modelling. WASP's latest version may be used in combination with other hydrodynamic programmes to model both hydrodynamics and pollution movement. Taipei University of Science and Technology recently combined the WASP model with the HEC-RAS hydrodynamic model (Liu et al., 2021). WASP has been shown in the literature to be capable of modelling transport in rivers, and it has often been integrated with a range of hydraulic evaluation tools for water quality simulation through external linking to hydraulic models for data on water flow. Among a few famous instances are those of:

Rodriguez and Peene (2001) coupled A two-dimensional, vertically averaged, hydrodynamic model using (EFDC) with a water quality model using (WASP). The model was developed for the Brunswick River, United States, in order to determine the TMDL for material demanding oxygen, taking into account the effects of PS paper mill, NPS, and estuary loadings, as well as benthic conditions. The model verified through simulation of salinity. The total allowable load for BODu discharges was 47,307 lbs/day to keep DO within acceptable limits, (Rodriguez & Peene, 2001).

Wool, Davie et al. (2003) used the Environmental Fluid Dynamics Code EFDC to analyse the complicated three-dimensional hydrodynamics of the Neuse River Estuary in North Carolina (USA). WASP was used to forecast nutrient cycling, eutrophication, and DO dynamics in the Neuse River Estuary. The models reproduced the spatial/temporal distribution of hydrodynamics and water quality with high accuracy based on a comparison between their simulations and the extensive dataset. Using the water quality model, TMDL scenarios were evaluated. During the years 1998–2000, there were no readings higher than 40 mg/L chl-a threshold, but there were some of fish deaths, (Wool et al., 2003).

Ernst and Owens (2009) Simulated chlorophyll a (chl a) and Total Phosphorus (TP) via SWAT and WASP that were most influenced by watershed, nine wastewater treatment plants, and atmospheric loading in the Cedar Creek Reservoir, Texas. An 11 years TP mass balance showed that the majority (87%) of TP came from nonpoint sources, followed by WWTPs (7%), sediment flux (3%) and atmospheric deposition (3%). Also, five systematic load reductions were simulated. Estimates of the nonpoint source reduction necessary for a significant reduction in Chla were about 30%, while estimates of reductions in OPO4 flux to significantly reduce Chla were 75–100%, (Ernst & Owens, 2009).

Fan et al (2009) assessed the water quality of a tidal river in northern Taiwan by combining the Qual2K model and the HEC-RAS model. In the Qual2K simulation, the (BOD), (NH3-N), (TP), and (SOD) contaminant loadings are utilised. The HEC-RAS model is used to: (i) estimate hydraulic constants for calculating atmospheric reaeration constants; and (ii) compute water level profile fluctuation to account for concentration variations due to tidal influence. The results indicate that HEC-RAS-assisted Qual2K simulations that account for tidal effect yield water quality indices that are generally consistent with the river's monitoring data, (Fan et al., 2009).

Yao, Zhuang et al. (2016) investigated the relationship between the concentration of 5 metals (Al, Ti, Ni, V, Pb) and turbidity in the Wusong and the Taipu Rivers of the Taihu basin in China. Information obtained at eleven locations along two rivers between January 2013 and June 2014 used through linear regressions. All the regressions presented good linear relationship, leading to the conclusion that the occurrence of the five metals was directly related to suspended solids, (Yao et al., 2016).

Quijano, Zhu et al. (2017) coupled the Environmental Fluid Dynamics Code (EFDC) with (WASP) to perform three dimensional simulations of the hydrodynamics and water quality in the Chicago River during storm events. The numerical model used to analyze the impact of combined sewer overflows for different storm's period, (Quijano et al., 2017).

Defne et al. (2017) used the Regional Ocean Modelling System (ROMS) and WASP together to conduct a complete water quality investigation in Barnegat Bay, New Jersey. The coupler combined hydrodynamic output from ROMS cells into bigger WASP segments in space. In ROMS output, the coupler aggregated discharge components, salinity, and temperature for input to WASP through a hydrodynamic linkage file. Utilising a WASP EUTRO model, the concentration of DO and nitrogen were investigated. Both upstream and at the entrance of the estuary, the surface layer has a higher simulated DO than the bottom layer. Simulated drops in total nitrogen (TN) near the estuary's mouth might have a negative impact on phytoplankton production of DO, (Defne et al., 2017).

Chueh et al. (2021) examined the copper distribution in Taiwan's Erren River by combining SWAT and WASP models. Copper was chosen as reactive parameter of the model, and many examples of copper effluent management situations and climate change's effects on copper concentration were simulated. SWAT was utilised to calculate NPS of soil erosion, which has a significant impact on the flow of a heavy metal via the River. WASP was utilised to simulate the concentration in aqueous and sediment phases of copper. Due to increased river flow, the aqueous copper concentration decreased as a result of climate change-induced increased precipitation, (Chueh et al., 2021).

4. Conclusion

After reviewing the previous studies conducted on the Shatt al-Arab River, the limitations can be summarized as follows:

- Some studies have not relied on the hydrodynamic model to describe the transport and distribution of pollutants by solving the flow governing equations.
- Some studies did not cover the total interested area of the entire Shatt al-Arab river.
- Some of researches have used a one-dimensional model to estimate the qualitative state of river water without giving more details about the correlation of pollutant reactions and the influence of some of them on the other.
- Most of the studies did not take into account the main source of River pollution, which is sewage that reaches it through branches inside the center of Basrah.
- Most of the studies relied on statistical analysis of data field in the distribution of pollutants on the river.
- The length of time interval of sampling, on average a month, does not give an adequate description of the changes in the pollutant as the effect of daily tides.
- Some studies assumed that the flow is a steady and the discharge values are constant value throughout the simulation period.

So, it is need to build a comprehensive model Addresses these points and describe the hydrological behavior of the Shatt al-Arab River as a first stage and then introducing different scenarios to face the River challenges such as establishment of environmental protection programs, and the implementation of regulations to control pollution. However, a limited number of studies have used multidimensional hydrodynamic and water quality models to physically simulate and predict contaminants transport. Prior to this point, there was no existing coupler that could connect HEC-RAS 2D with the WASP framework (Shabani et al., 2021). This work recommended to build an integrated two-dimensional simulation model connects

HEC-RAS with WASP software due to the complexity characteristics of the Shatt al-Arab River. Where, this method has not been used in previous studies. The model connects the HEC-RAS software, which is known for its competence in modeling complex two-dimensional situations, with the WASP program, which has a high ability to represent a wide range of water pollutants that HEC-RAS cannot represent, especially in a two-dimensional model.

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